US energy security

Problems and prospects

Ira Sohn

Despite the impression conveyed by the data on US energy – particularly oil – consumption and production over the last three years, and the increased concentration of excess capacity and reserves in the Persian Gulf countries, the prospects for the USA and other OECD oil-importing countries to satisfy their energy requirements in the short term are favourable. As a result of the projected energy efficiency gains in manufacturing and transportation, continued electrification of the economy – fueled increasingly by nuclear and solar energy, and mounting environmental problems over the use of fossil fuels, the longer term prospects regarding US energy security are even more encouraging.

Keywords: US energy security; Energy efficiency; Alternative fuels

The rise in the price of timber in the thirteenth century put pressure on the society to find a new fuel. Coal was found. **(Jean Gimpel)**[1]

More serious calculations than mine have shown that coal did not overtake wood in the economy of the United States until 1887! **(Ferdnand Braundel)**[2]

As we enter the last decade of the 20th century, the release of some very recent data concerning US energy consumption and production has sounded a renewed alarm forewarning the potential for yet another energy crisis in the near future. The seriousness with which these recent data are being examined and analysed has already led to the publication of a number of studies on this subject from both official and independent investigations.[3]

If, as we shall see below, the disturbing data of the last two or three years are viewed in a wider context which incorporates the efficiency gains in energy use since 1973; the increased awareness, at the highest policymaking levels of the US government, of the increasingly complex environmental issues caused, to a great extent, by burning fossil fuels; the current and future prospects for natural gas and nuclear energy; the current and projected future supply and demand patterns for oil; and the increasing electrification of the US economy (including new and improved sources of electricity), the march of time, guided by 'proper' government policies should, over the next half century, once and for all, reduce significantly, if not eliminate entirely, the recently renewed spectre of gasoline lines, selected power outages, reduced working time and other restraints on energy demand witnessed by many of us during the 1970s.

In fact, after viewing this information in a comprehensive way the progress made by the USA (and other OECD countries) since 1973 in enhancing energy efficiency and reducing the risk of an energy shortage has not only exceeded expectations but, as will be observed below, the 'best is yet to come'.

In assessing US energy data of the last 15 years compared with the data of a similar interval of time (1960–73) that culminated in the first energy crisis, despite some recent, entirely explainable setbacks in US energy supply and use and in spite of the perception that the US and other energy-importing OECD countries are aimlessly 'wandering in the desert' with regard to a long-term solution to their energy requirements, like the ancient Israelites, their 'Promised Land' is very much in sight and is likely to be attained, given the proper incentives, in the next century.

This paper reviews some of the standard indices of US energy consumption over the last 30 years, highlights the alleged alarming trends of the last three years, and provides a detailed description and analysis of the changing structure of energy feedstocks, use and supply in the USA since (1960, where possible and from) 1973 to the present. The opportunities that are available to the USA because of institutional and technical changes that have been

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introduced into the international oil market since 1973 combined with a description of the political, economic and financial environment – in a global sense – which is likely to prevail in the 1990s are also presented. All of these short- and medium-term considerations argue against, at least through the medium-term, a serious oil disruption or price increases similar to those experienced in 1973 and 1979. In conclusion the paper focuses on some emerging energy sources and energy efficiencies likely to be realized in the USA over the next half century.

US ENERGY CONSUMPTION (1960–88)

In reviewing the data on US energy consumption over an approximately 30 year interval of time (1960–88), the data in Table 1 portray a sharp line of demarcation that separates the period before the first energy crisis (in 1973) with the succeeding 15 years. This is the case even for oil consumption in the transportation sector, whose acknowledged problem is the lingering absence of a competitively-priced substitute fuel. In 1988, over 97% of the total energy consumed in the transportation section was derived from oil. Admittedly, since the crash in oil prices in 1986, compounded by some policy errors in Washington (some of which have already been rectified by the Bush Administration), there have been some setbacks relative to the late 1970s and early 1980s in the use of energy throughout the US economy.

A similar message is conveyed by examining the annual rates of growth in total energy consumption per capita (Table 1, column 5). In the wake of the 1973 oil crisis, higher energy prices led to increases in energy efficiency and to a displacement of many energy-intensive industries in favour of (less-energy intensive) service industries in the US economy. The combined effect of these changes is presented in column 6 of Table 1. The entries in this column tell the following story: during the 1960–73 period, total energy consumption grew at the same rate as GNP, while during the 1973–88 period, total energy consumption grew more slowly than the growth in GNP. Figure 1 presents an overall picture of gains in energy efficiency from 1970 to 1988 in OECD countries and developing economies.

THE CHANGING STRUCTURE OF US ENERGY FEEDSTOCKS AND CONSUMPTION BY END-USE SECTORS (1960–88)

Changes in major energy sources

Table 2 presents the evolving pattern of energy consumption by major energy sources as a percentage of total energy consumed in the three benchmark years – 1960, 1973, and 1988. The increasing consumption of electricity, which is both an indirect source of energy as well as an end-use sector, is included in column 6 of this table. This 30 year interval has witnessed an increasing electrification of the US economy: in 1960, only 18.7% of total energy used in the USA was consumed as electrical energy while as of 1988, the percentage was almost double the 1960 rate. On an annual basis, energy consumed by electrical utilities as a percentage of total US energy consumption has been growing at a rate of 2.3% from 1960–88.

A few salient remarks on some of the entries in Table 2 are in order. Since 1973 the increasing electrification of the US economy has been supported by an increasing use of coal and nuclear energy displacing petroleum and natural gas in that sector. (More about this below.) The sharp drop in the share of natural gas from 1973 to 1988 can be attributed, in part, to supply shortages created by regulatory measures only now being removed. The share of petroleum in the US energy balance over the 30 year interval – despite two sharp price increases and one sharp price reduction – has remained virtually unchanged. This can be explained by the increasing share that the transportation sector of the economy is absorbing of total petroleum

Table 1. Consumption of energy by end-use sector (rate of growth/year).

Year	(1) Total energy consumption	(2) Residential and commercial	(3) Industrial	(4) Transportation	(5) Energy consumption (per capita)	(6) Energy Consumption (per dollar of GNP)
1960–73	4.1%	4.85%	3.5%	4.4%	2.8%	0
1973–88	0.4%	1.50%	0	1.1%	0	−0.02%
1985–88	2.6%	2.90%	2.2%	2.8%	1.6%	−0.01%

Source. *Annual Energy Review 1988*, DOE/EIA-0384(88), Washington, DC, USA.

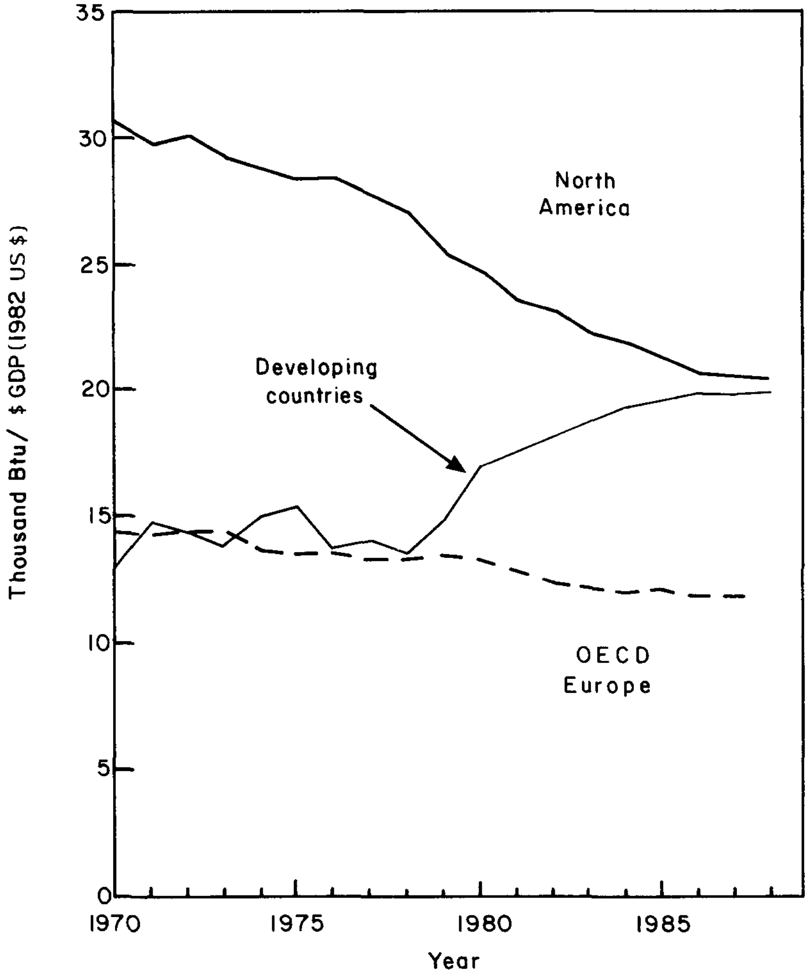

Figure 1. Energy intensity in selected regions (1970–1988).
Source: Annual Energy Outlook 1989, (US Department of Energy)

consumed. According to the US Department of Energy (DOE),[4] motor gasoline and jet fuel absorbed 52.4% of total petroleum consumed in 1960 and 62.4% in 1988. On the other hand, the share of petroleum used as residual fuel oil (for commercial and industrial heating and electricity generation) declined from 15.6% in 1960 to 7.7% in 1988.

Turning to columns 7 – 9 of Table 2, while the US economy becomes more 'service' oriented, an increasing percentage of total energy is being consumed in the residential–commercial and transportation sectors. In 1960 these two sectors consumed 54% of total energy; by 1988, almost two-thirds of all energy consumed in the USA was absorbed by these two sectors.

Table 3 describes the changing allocations of fossil fuel feedstocks into four end-use sectors in 1960, 1973 and 1988. Today more than 85% of domestic coal demand is consumed in the electricity sector as the direct use of coal recedes in industry and commercial and residential buildings. Natural gas

Table 2. Energy consumption by major sources and end-use sectors as a percentage of total energy consumption; 1960, 1973 and 1988 (%).

	Major sources						End-use sectors		
	(1)[a]	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Year	Coal	Natural gas	Petroleum	Hydro-electric	Nuclear	Electricity	Residential and commercial	Industrial	Transportation
1960	22.4	28.3	45.5	3.8	0	18.7	29.8	46.0	24.2
1973	17.4	30.3	46.9	4.0	1.2	26.7	32.5	42.4	25.0
1988	23.5	23.3	42.5	3.3	7.1	35.8	36.4	36.2	27.3

Notes:[a]On any given row both the sum of the percentages in the first five and the sum of the last three columns equals 100%.
Source: Annual Energy Review 1988, DOE-EIA-0384, 1988, Washington, DC, USA.

Table 3. Fossil fuel consumption by end-use sector; 1960, 1973 and 1988 (%).

Fossil fuel	Year	Electrical utilities	Industry	Transportation	Residential and commercial
Coal	1960	44.4	44.6	0	10.3
	1973	69.2	28.8	0	2.0
	1988	85.9	13.3	0	0.9
Natural gas	1960	14.4	48.2	2.9	34.4
	1973	16.6	46.2	3.3	33.9
	1988	14.6	41.8	3.0	40.5
Petroleum	1960	2.4	27.6	52.4	17.4
	1973	8.9	25.9	52.3	12.9
	1988	4.0	25.4	62.4	8.2

Source: *Annual Energy Review 1988*, DOE/EIA-0384(88), Washington, DC, USA.

has been the most stable of the three fossil fuels. The share of natural gas taken by the electricity and transportation sectors is essentially unchanged over the 30 year interval while the reduced share in industry was offset by an increased share in residential and commercial buildings. Turning to the use of petroleum products, since 1973, the share of petroleum absorbed by electric utilities and residential and commercial buildings declined by 50% and 33% respectively. These reductions were offset by a 19% increase in the share of petroleum absorbed by the transportation sector where almost two-thirds of all petroleum products are consumed. The share of petroleum used in the industrial sector has remained virtually unchanged since 1960.

With respect to energy consumption in industry in the three bench-mark years, according to the DOE,[5] in 1960, 33% of total energy consumed was derived from petroleum products *v* 39% in 1987. This same stability was exhibited by natural gas with 34% to 40% of total energy consumed in industry being derived from natural gas in the three bench-mark years. Direct coal deliveries to industry have fallen steadily over the interval, and as a result, the share of coal as a direct energy input in industry in 1987 declined by 42% since 1960, at which time more than a quarter of all energy absorbed by US industry was direct consumption of coal. Just as there has been a steady decline in the share of coal as a direct energy input into the industrial sector there has been a steady increase in the use of electricity as a source of energy into this sector. In 1960, only 6.5% of the energy consumed by US industry was electrical while in 1987 that share had doubled.

Natural gas in 1987 continued to provide half of total household energy requirements. Petroleum-based fuels continue to recede in importance as an energy source in the residential sector: in 1960, 34%, in 1973, 28%, while in 1987, only 17% of the residential sector's total energy requirements were petroleum-based.

Electricity continues to increase its share of total energy consumed by the household sector: in 1960, 10% and in 1973, 20% of households' total energy consumption was electricity-based, while by 1987 that share was over 32%. In addition to the feedstock changes since 1960, the absolute level of energy (in millions of BTUs) increased from 124.5 in 1960 to 135.1 in 1975 and declined to 99.9 in 1987, a reduction of 1%/year over the entire interval.

The changing profile of energy consumption in commercial buildings is similar to that in the residential sector.[6] In 1960 and 1973, fuel oil contributed approximately 36% and 26%, respectively, to total energy required by the commercial sector, while in 1987 that share declined to 17%. The shares of electricity and natural gas in the energy budget of the commercial sector in 1960 (and 1973) were 16% (26%) and 31% (45%), respectively. In 1987 these shares were 41% and 40%, respectively.

Turning to transportation, it was observed in Table 2 that the share of total US energy consumption absorbed by the transportation sector increased from 24.2% in 1960 to 27.3% in 1988. According to Gately,[7] today, two-thirds of US oil consumption is used in the transportation sector, an increase of over 10% in the share from 1960 and 1973. The increased share is, in large part, attributed to the interfuel substitution implemented by the industrial, residential and commercial sectors in response to the 1973 and 1979 oil price increases. With no close competitive substitute for oil, the transportation sector has been forced to seek improvements in fuel efficiency to reduce (or slow the rate of increase of) oil consumption since the 1970s. Despite an increase in total vehicle registrations of 2.5%/year from 1973–88, total motor fuel (gasoline and other fuels) consumption increased by only 1.1% over the same interval. This is an impressive improvement in fuel efficiency if measured by the figures of 1960–73 in which total motor vehicle registrations increased by 4.4%/year while fuel consumption increased by 4.7%/year. Despite a 3.6% increase in the average number of miles driven per vehicle from 1973–87, fuel consumption (in gallons per vehicle) *decreased* more than 20% over the same interval. This translates into a 17.1% increase in miles per gallon (mpg) from 1973–87 or an annual increase of 1.1% over the 14 year interval. For passenger cars, which comprise about three-quarters of all registered motor vehicles, the increase in mpg was even more impressive: a 44% increase from 1973–87 or an annual increase of 2.7% over the interval.

In 1988, US demand for jet fuel reached 1.45 million barrels a day (mbd), or approximately 8.5% of total US oil consumption. Jet fuel consumption has been increasing at an annual rate of 2.1% over the 15 year interval ending in 1988. During this interval both passenger miles and seat miles – two standard indices used by the airline industry – increased more than 5%/year, which can be attributed to higher income levels, airline deregulation and technological change. These latter two causes led to substantial reductions in the *real* price of airline tickets. According to Gately,[8] jet-fuel efficiencies have occurred in several ways. Airplane fleet composition has shifted toward more fuel efficient airplane types: for example, the Boeing 747 is twice as fuel-efficient as the Boeing 707. In addition, the newer 747s are more fuel efficient than their older prototypes. Also, there has been substantial upgrading of existing airplanes through retrofitting of engines and increases of 10 to 30% in the number of seats per plane since 1965.

The changing structure of energy supply

Table 4 traces the changing annualized rates of growth of the various sources of energy used in the US economy from 1960–88. Since 1973, coal output increased almost 50% while total US energy output increased only 6.1% over the same period. To a large extent the increase in coal output reflects the substitution away from natural gas and petroleum in the electricity sector. Regarding natural gas output, as was mentioned above, the regulatory climate to date served as a major explanation of the poor performance of this sector since 1973. (More about the future prospects for natural gas below.) Turning to crude oil and natural gas liquids products (columns 3 and 4), the negative growth rates for 1973–88 are worse than the numbers suggest because throughout most of this period petroleum prices were at their historically highest level. Domestic production of crude oil in 1985 was still below the peak production years of 1970–72, despite the price increases of 1973 and 1979. The impact of the 1986 crash in oil prices is seen in the 3.2%/year *decrease* in domestic crude oil production from 1985–88. The brightest star in the US energy firmament over this 30 year period has been nuclear power production, which registered a solid 13% annual rate of growth since the first energy crisis in 1973. However, due to a poor financial and regulatory environment and safety-related problems (both real and imagined) that overwhelmed the nuclear energy industry in the 1980s, growth rates of nuclear energy production in the 1990s are certain to be much below the solid performance of the late 1970s and early 1980s.

The last column of this table provides the basis for the topic of this paper, US energy security. In 1960, the percentage of US petroleum imports to total petroleum products supplied was 16%; by 1972 that percentage reached 36% and by 1988 that percentage, despite a reduction in import levels throughout the 1980s, was more than 36%. The implications for US energy security of stagnant or even declining US domestic production along with increasing oil consumption in the 1990s and beyond is examined below.

Table 5 presents the evolving structure of 'feedstock fuels' used by electrical utilities in 1960, 1973, and 1988. There are few surprises in the numbers appearing in this table. Since the 1973 energy crisis, coal and nuclear energy were increasingly substituted for high-priced petroleum and supply-constrained natural gas (which was subjected to price controls dictated by regulatory agencies). Barring major increases in the price of other energy feedstocks, the share of electricity generated by hydroelectric capacity is expected to continue to decline through the 1990s as has been the trend over the last 30 years. The potential for coal, natural gas,

Table 4. Production of energy by major source; 1960–88 (annual percentage change).

Year	(1) Coal	(2) Natural gas	(3) Crude oil	(4) Natural gas plant liquids	(5) Hydro-electric power	(6) Nuclear electric power	(7) Net imports of petroleum
1960–73	2.0	4.4	2.1	4.4	4.5	41.0	10.4
1973–88	2.7	−1.7	−1.7	−1.0	−1.4	13.0	0
1985–88	2.7	0	−3.2	0	−7.6	11.0	14.5

Source: *Annual Energy Review 1988*, DOE/EIA-0384(88), Washington, DC, USA.

Table 5. Changing energy feedstocks in electric utilities; 1960–88 (%).

Year	Coal	Natural gas	Petroleum	Nuclear	Hydro-electric	Totals[a]
1960	53.3	20.9	6.3	0	19.3	100
1973	45.6	18.3	16.9	4.4	14.6	100
1988	56.9	9.4	5.5	19.5	8.2	100

[a] The row totals are rounded to 100%

Source: *Annual Energy Review 1988*, DOE/EIA-0384(88), Washington, DC, USA.

nuclear and solar energy in the US electricity sector in the 1990s and beyond is discussed later.

Despite the enhanced energy efficiency of the US economy since 1973 brought about by interfuel substitution and technological change in both energy-producing and using sectors, the data presented in Figure 2, combined with the trend in US energy consumption and production from 1985 to date, give the appearance that the US and other OECD oil-importing countries are becoming vulnerable to possible oil supply disruptions and/or large oil price increases similar to those in the 1970s. With 73% of current global oil reserves concentrated in OPEC and 67% of current global natural gas reserves located in the USSR, the Middle East and Africa, this might provide support for the claim that the US and other oil-importing OECD countries are facing an uncertain future regarding deliveries of these two energy feedstocks. This paper will argue to the contrary: that is, due to a constellation of economic, financial, political, environmental, strategic and technological forces – of a global nature – it is likely that we will observe a gradual deceleration in the rate of growth of fossil fuel use – including petroluem – in the developed market economies over the next 25 to 50 years. This is not to say that the global economy of the 1990s will be immune to price volatility (and/or periodic shortages or surpluses) in the oil market in particular and energy markets in general, but as we will explore later, the ongoing electrification of the US economy which is likely to be fueled increasingly by solar and nuclear energy, combined with continuing energy innovations and efficiencies in manufacturing, transport and domestic appliances will not only reduce the rate of growth in consumption of fossil fuels, but, given sufficient time – combined with the environmental concerns now being voiced – we will witness the beginning of the end of fossil fuels as the major source of energy used to fuel the developed market economies. We now turn to an overview of the major short- and medium-term measures and contingencies that can be employed to reduce the threat of a major oil-supply disruption in the USA and other oil-importing developed economies during the next decade.

THE ENERGY ENVIRONMENT IN THE 1990s

Opportunities and constraints

As far as US energy security is concerned, according to some of the standard energy indices, the US economy is increasingly exposed to potential disruptions in oil deliveries. Figure 3 traces the evolving share of total oil consumption satisfied by net imports and net imports from OPEC as a share of total net imports. According to a recent study by the

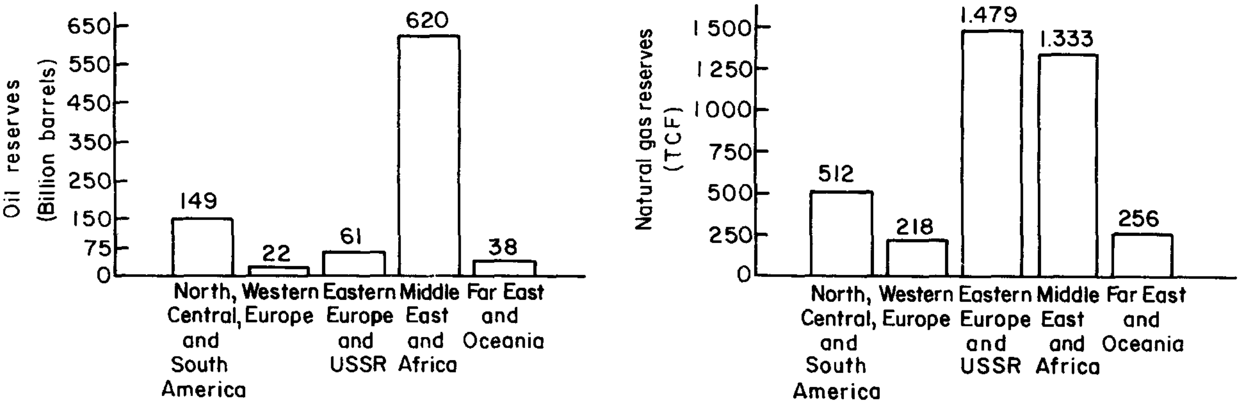

Figure 2. World oil and natural gas reserves (1 January 1988).

Sources: Oil and Gas Journal, various issues; and *Annual Energy Review 1988*, DOE/EIA-0384, 1988

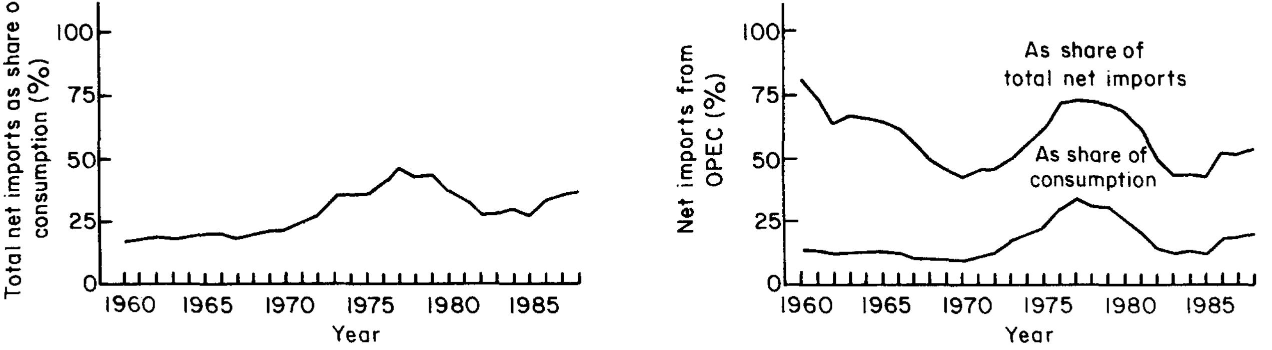

Figure 3. Total net oil imports as share of consumption and net imports for OPEC.
Source: Annual Energy Review 1988, DOE/EIA-0384, 1988

US General Accounting Office[9] (US GAO), because of increased oil consumption and the projected continued decline in US crude oil production, net oil imports as a percentage of total US oil consumption is projected to reach almost 55% by 1995.

Since oil is a globally traded commodity, shortages (surpluses) occur when world consumption exceeds (falls short of) world production. Then prices increase (decrease), reducing (increasing) consumption and/or more (less) productive capacity is utilized to balance output with consumption at existing or different prices. The ability to increase production in the short-run is dependent on the level of excess productive capacity. Figure 4, which describes the distribution of world excess productive capacity in 1987, suggests that, in addition to oil *reserves*, global excess productive capacity is increasingly concentrated in OPEC. Lower costs, eg, improved technology, improved transportation and distribution networks, and/or higher prices are likely to increase global oil reserves and world productive capacity. For example, in 1960, global oil reserves approximated 300 billion bbl of oil; in 1989 global oil reserves were estimated at 900 billion bbl, a 3.9% annual rate of growth over the period.[10] One recent study noted that estimated global oil reserves increased 30% just in the last three years.[11] Over the 40 year period ending in 1987, even the US reserve base has increased by an average of 1%/year.[12]

If, as expected, oil prices remain within their current range over the medium term, the share (*and* the amount) of world oil produced in the OECD countries (including the USA) is likely to decline in

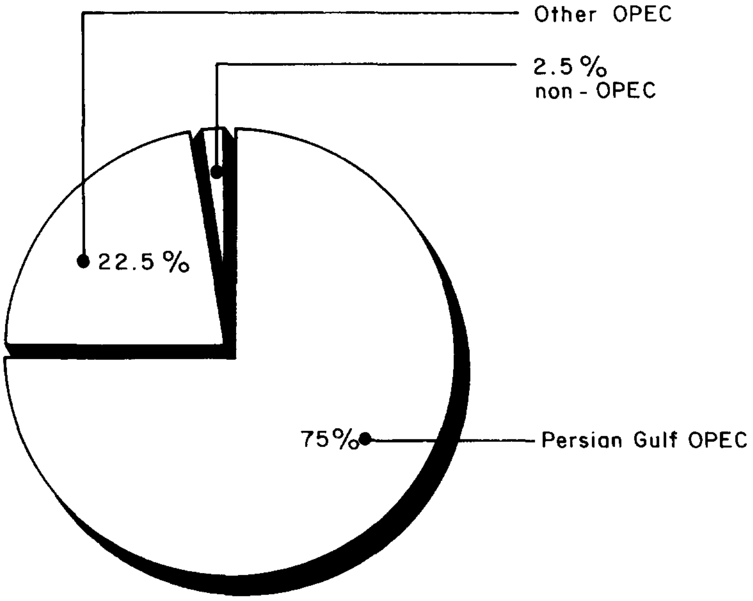

Figure 4. World excess production capacity, (8–10 million bbl/day) 1987.
Source: Energy Security (GAO/RCED-88-170).

the future and production will be increasingly concentrated in the areas of the world in which the largest reserve bases and excess productive capacity are found, ie, OPEC, and more specifically, the Persian Gulf. However, because of the recent development of alternative modes of transporting oil from the Persian Gulf, ie, by pipeline, even oil originating in that area is today much less vulnerable to a suspension of tanker traffic. By this year, pipeline capacity in the region will be 6.1 million bbl/day compared with less than 1.0 million bbl/day in 1980.[13] Another important stabilizing influence on the supply of OPEC oil to Western markets is the level of investments made by several OPEC countries in down-stream activities, ie, refining and distribution, in oil-importing countries.

Another reason that argues against an oil supply disruption (or even a large 'extra-market' increase in oil prices) in the short- (and even medium-) term is the well-known inability of OPEC to restrict its actual output in accordance with announced levels, the result of the very different economic, financial and political circumstances that member countries of the oil cartel must confront. For example, Nigeria and Venezuela, for whom oil revenues in 1987 constituted 95% and 85%, of total export revenues, respectively, are dependent on oil sales to service their heavy debt burdens.[14] Or, on the other hand, the increasing need for hard currency, for both Iran and Iraq, to rebuild their war-ravaged economies, has created problems in OPEC to insure compliance with their alloted quotas. (Iraq is unhappy with its quota of 2.6 million bbl/day when its capacity is equal to 5.0 million bbl/day.)

According to the GAO,[15] the most significant institutional development since 1973 to respond to a renewed oil flow disruption has been the stockpiling of oil by the governments of the major industrial countries, in particular the Strategic Petroleum Reserve (SPR) of the USA which, by 1995 is expected to have 750 million bbl of oil, approximately 45 days of current consumption. Some oil experts are arguing that the level of oil stocks in the SPR should be tied to the level of US oil imports, since it is imports that would have to be replaced in the event of a sudden interruption in oil deliveries. Drawdowns from the SPR are likely to be complemented with government-imposed restraints on demand, almost certainly on gasoline for automobiles. Similar efforts are under way or are planned by Japan, West Germany, France and Belgium.

Also of importance in coordinating efforts on a supra-national basis in confronting a short-term interruption in oil deliveries to OECD countries is the International Energy Agency (IEA), established in the wake of the first oil crisis. Among the measures the IEA has developed is the Emergency Sharing System, that could limit disruption-induced price increases. As the GAO report[16] stated:

> The mere existence of an international agency dedicated to coping with energy crises can help deter politically motivated disruptions directed at one or more member countries.

However, despite the IEA machinery that is in place to oversee the response to an oil crisis, there exist deep policy differences between the US and European members over the use of demand restraints, ie, reducing consumption, *v* early coordination in using oil stocks, ie, increasing supply, to restrain the pressure on oil prices.

Another medium-term measure that could be introduced to reduce US vulnerability to oil imports is the much touted oil-import fee (or variable import tariff) that would provide production incentives to US oil producers because of the resulting increase in oil prices. The tenuous argument of national security notwithstanding, this measure would be difficult to justify on economic and/or political grounds.

An increased gasoline tax – with the additional revenues dedicated to building and maintaining highway infrastructure and/or to finance environmental programmes – would, at least in the short-term, reduce gasoline consumption (and oil imports) and, in the medium-term, would provide incentives to automobile producers to design and manufacture more fuel-efficient automobiles. While not underestimating the political difficulties involved with this tax, if enough of Washington's interest groups can be persuaded of its long-term benefits, with bipartisan Congressional support and strong backing from the Administration, it could be approved and implemented. It is important to note that (at exchange rates existing in December 1988) gasoline prices in New York were 27% those of Tokyo, 29% those of Milan, and 34% those of Paris.[17]

Another short-term measure that has been and continues to be employed by the USA to reduce the risk of a politically-motivated interruption in oil deliveries is a diversification of its sources of imported oil – between OPEC and non-OPEC oil exporters and within OPEC itself. However, barring significant oil price increases and/or technological improvements in locating, extracting and transporting oil, this policy is of limited usefulness because of the evolving domination of the Persian Gulf states in excess productive capacity and reserves in the approaching 21st century. According to Edward Fried of the Brookings Institute,[18] by the year 2000, US oil production is likely to range between 6 and 8 million bbl/day, while imports are expected to range between 9 and 14 million bbl/day, with greater and greater concentrations coming from OPEC in general and the Persian Gulf in particular, since both North Sea and Alaskan oil production are expected to be in decline by then.

Recognizing that the oil market is global in scope, yet another medium-term measure available but not heretofore employed by the US and other OECD oil-importing countries is the economic and financial pressure that can be applied to both Eastern bloc and developing countries to insure that these countries, some of whom are recipients of official credits (from governments and international development organizations such as the World Bank), adhere to certain internationally acceptable oil (and/or energy) efficiency standards in their respective economies. Table 6 compares the changing energy intensity of the USA, OECD Europe, the USSR and the developing economies from 1970 to 1988. As an important by-product, imposing international standards will also have environmental benefits – a subject to be examined below. Similar schemes, focusing directly on protecting the environment have already been implemented in Costa Rica, Bolivia, the Philippines, Brazil, and most recently, Madagascar.[19]

Among the other short-term measures available to the USA, and more importantly to Europe and Japan, is the fuel-switching capability in industrial boilers and electric utilities. The scope for further substitution out of oil in electric utilities in the USA is already limited since fuel oil is the source of only 5.5% of total US electricity generated, which was equivalent to some 8% of total US oil consumption in 1988. According to Gately,[20] in industrial countries other than the USA, residual fuel represented 18% of total oil consumption in 1987, and in Japan, in particular, 27% of its total oil consumption was absorbed in electrical utilities.

The major focus of US energy policy in the medium- and long-term should be centred on promoting energy efficiency and developing alternative fuels – particularly in the transportation sector, the only sector of the US economy that has continued to increase its consumption of oil during the last 10 years. Given the recent pronouncements regarding the environmental impact of gasoline fumes, reducing gasoline consumption in the transportation sector is today even more critical – a subject explored in the Appendix.

Table 6. Changing energy intensity, 1970–88 (thousand Btu's/1980 $ of GDP).

Country (region)	1970	1975	1980	1985	1988
USA	31.9	30.5	28.3	25.0	23.1
OECD Europe	16.8	15.8	15.6	14.3	13.9
USSR	na	38.5	42.3	44.3	43.3
Developing countries	16.3	16.1	16.5	19.8	19.9

Source: US Department of Energy, Washington, DC, USA.

EMERGING ENERGY SOURCES AND EFFICIENCIES

We now examine the current prospects for some long-term solutions to US energy (and environmental) problems. In fact, according to some political observers, proposed US environmental policy is the driving force that is forging current US energy policy.[21] These long-term solutions include an increasing use of electricity – both nuclear and solar generated – new uses of natural gas, and the prospective gains in energy efficiency in US manufacturing into the 21st century. These prospects, if successful, combined with the increasingly stringent fuel efficiency and pollution standards being proposed, are likely to simultaneously improve the quality of the environment and enhance the energy security of the US and other oil-importing developed countries.

New and improved sources of electricity

Over the interval of 1960–88 US electricity consumption increased at an average annual rate of growth equal to 4.8%. Since the first energy crisis in 1973, despite a lower *level* of oil and natural gas consumption, electricity consumption continued to increase, albeit at a more modest 2.7%/year, approximately the same average annual rate of growth in US GNP. Since 1973, the enhanced electrification of the US economy has been fueled by an increased output of nuclear energy (a 13% annual rate of growth) and increased coal deliveries (a 4% annual rate of growth) to generate the increased electricity output. Because of environmental problems, the continued burning of fossil fuels (in particular coal), must be either modified – by using low sulphur coal or retrofitting utility plants with the appropriate antipollution equipment – or reduced (over the long-term) in favour of safer and more economical ways of generating electricity. One source that is beginning to look more and more promising is photovoltaic energy (PV), which according to Hubbard,[22] 'within 20 years, should become one of the world's preferred technologies for generating electrical energy (for central station peaking power)'. According to Hubbard, despite the well-known problems of land-area requirements, utility grid compatibility, solar resource intermittency and storage, the cost of photovoltaic-generated electricity will soon be competitive with baseload power from conventional sources. In 1973, the cost of electricity generated from solar sources was $15 kWh, today the cost is 30¢ kWh! The first utility-scale demonstration plant in the USA is expected to go on-line this year.

Some of the acknowledged attributes of PV are:

1. Relatively short lead-times (1–2 years) to bring 1 GW of capacity on-line;
2. PV is 'environmentally friendly';
3. At first, they will serve as an alternative for peak electricity production, when electricity from conventional sources is most expensive;
4. Once installed, PV has low operating and maintenance costs;
5. PV-generated electricity is immune to supply disruption;
6. PV-generated electricity is also immune to fuel cost escalations.

Assuming that the proposed strict air-pollution standards will be adopted in the USA, the cost (and therefore price) of fossil-fuel-generated electricity is likely to increase, making the economics of solar energy more and more attractive as we enter the 21st century. Less expensive and cleaner electrical energy will also strengthen the case for the introduction of electricity- (and even hydrogen-) powered automobiles, which already today can travel up to 70 miles (112 kilometres) without refueling. These 'alternatively-fueled' vehicles are likely to be introduced, at first, in fleets for urban driving, which are currently the most polluting and travel the least mileage per day.[23]

Nuclear, another proven energy source that has been plagued by financial, regulatory and safety problems in the 1980s is poised to assume a leading role in providing safe, clean and competitively-priced electrical energy for the USA in the 21st century. As the US nuclear industry rationalizes plant production according to standardized designs – to ease licensing procedures – higher operating capacities of 75–85% in place of the existing average of 60% can be assured. In addition, as the regulatory climate is made more rational and orderly, the new, smaller (250 MW capacity), longer-lived (60 years), safer and easier to operate nuclear technology will once again be competitive with other sources of electrical energy.

New uses of natural gas

With the last of the regulatory impediments – initiated in 1954 – on natural gas prices being removed, the fuel will finally be permitted to find its proper role in the energy profile of the USA. The regulatory environment for natural gas in the 1960s and 1970s was so poor that exploration was discouraged, reserves appeared to be dwindling and, because of supply disincentives, deliveries fell from 1972–87, when the regulatory environment become favourable for exploration, production and distribution of natural gas. According to the DOE,[24] today, the 'technically recoverable resource base of natural gas in the lower 48 states represents a greater than 50-year supply at the current usage rate'. In the last 10 years, world reserves of natural gas have soared by more than 50%.[25] Increased supplies of natural gas along with the development of new technologies are likely to lead to an efficent use of natural gas in both traditional and new applications. Natural gas (or its derivative, methanol) is the cleanest of the fossil fuels, and is therefore likely to find new uses in the transportation sector, the sector that is most critically dependent on oil. As has already been mentioned, distribution problems do exist for refueling automobiles, but as in the case of the electric car, natural-gas-powered automobiles are likely to find their niche in large fleets of transit and delivery vehicles where centralized fueling exists. The 1990s are likely to see the introduction of natural gas for residential and commercial cooling. (In 1987 natural gas was used for heating in more than half of all American single-family homes.) New opportunities also exist for natural gas in industrial electricity generation as a combined-cycle system to produce power and process heat.[26]

Natural gas is also expected to assume a larger role in the European electricity grid – where substantial fuel-switching out of coal and oil exists – as deliveries of Soviet and Algerian natural gas increase in the 1990s. According to *The Economist*,[27] close to 20% of European electricity may be gas-fired by 2020, while only 3% is today. Once again it needs to be recalled that since oil is a globally traded commodity, a reduction in global demand, *ceteris paribus*, exerts downward pressure on global oil prices.

Prospective energy efficiencies in manufacturing

Having examined some of the new (and improved) technologies to produce electricity in an increasingly electrified economy and some of the prospects for reducing oil consumption in the transportation sector – through enhanced gasoline efficiency and the introduction of non-oil powered automobiles in the 21st century – what are some of the prospects for improving energy efficiency in the manufacturing sector, which, in 1988, consumed 36% of total US energy and 34% of total electricity. These prospects will also have an indirect impact on future US energy security and environmental concerns.

Figure 5 provides an overview of the energy intensity of the US manufacturing sector from 1958–85. Even though US energy intensity fell by a third between 1972–85, fossil fuel intensity fell by half over the same period, due, in part, to a relative shift away from energy intensive production activities such as aluminium smelting. Figure 6 describes both fossil fuel intensity and electricity intensity in US manufacturing from 1958–85. Despite the increasing electrification of the economy throughout the entire period, due to gains in energy efficiency and the relative decline of energy-intensive activities, energy intensity in the US economy at large declined from 1970–88. (See Table 6.)

Where and what are the remaining opportunities to improve US energy efficiency in the manufacturing sector? According to Marc Ross,[28] 'the cost-effective opportunity now available is larger than the savings so far achieved'. For example, despite the fact that the US steel industry has achieved a 21% reduction in energy use per tonne of output from 1972–85, a reference plant in which the best cost-effective technology is used requires 39% less energy per tonne of output than the current US average.[29] Also, power consumption in the 'best practice' plant has dropped 25% in 20 years.[30] According to Ross:

> efficiency improvements in the fabrication and assembly of automobiles (that is, starting from basic materials such as steel and plastics) are under way which should reduce the electricity intensity by about 30% at present prices. In Japan, with electricity prices almost double those here [in the US] (compared by using purchasing power parity rather than the exchange rate), the electricity intensity of comparable activities is actually 50% less than in the United States.[31]

Another major new inroad for electrification – cogeneration of heat and power – which is another way to reduce US energy intensity, was mentioned earlier.

CONCLUSIONS

Observing in isolation the future global supply pattern of oil, ie, the heavy concentration of both excess productive capacity and reserves in OPEC (and perhaps more dangerously, in the Persian Gulf), US energy (or at least oil) security prospects look bleak indeed. However, this is only one small part of a much larger picture. Taking into account not only the logistical changes that have taken place

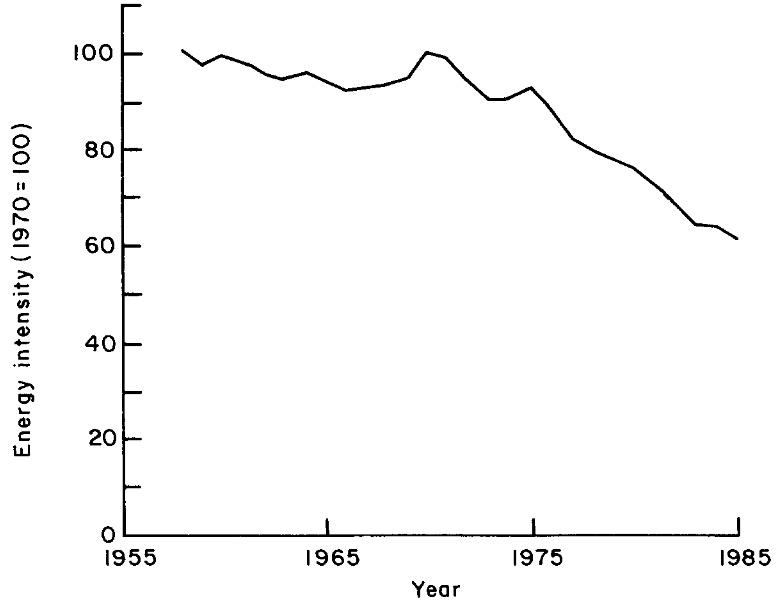

Figure 5. Aggregate energy intensity of US manufacturing, 1958–1985.
Source: Science, 21 April 1989.

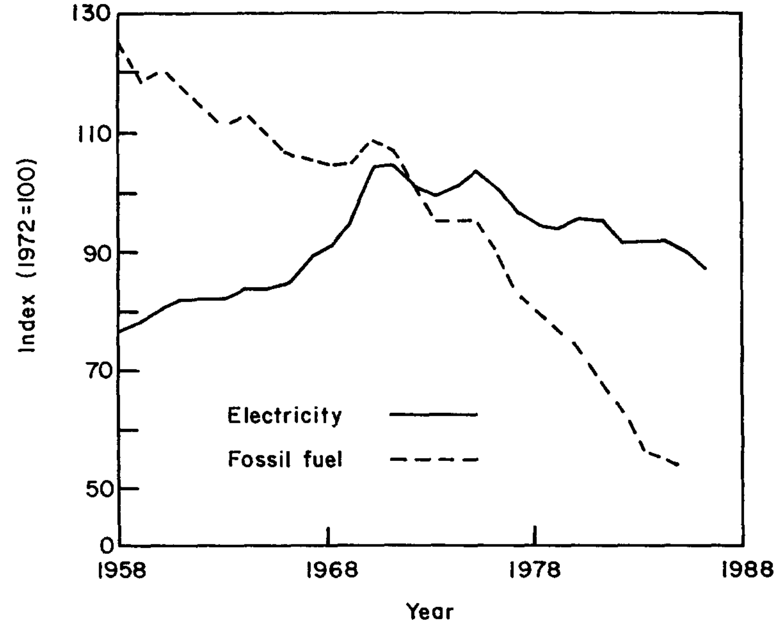

Figure 6. Aggregate electricity and fossil fuel intensity of US manufacturing, 1958–85.
Source: Science, 21 April 1989.

over the last 10 years in securing the deliveries of oil from the Persian Gulf, but also the very different needs and constraints of the members of OPEC, US oil vulnerability in the short and medium term is relaxed a shade. Introducing into this framework the very real environmental problems attributed to the use of fossil fuels in electric utilities, manufacturing and transportation and the recent national and multi-lateral proposals to confront this problem within a global context, the threat of another energy crisis in the longer-term is reduced yet another tick. Incorporating the prospects for fuel substitution in automobiles – natural gas, electric and later on, hydrogen-powered vehicles – and the continued enhancement of energy efficiency throughout the manufacturing sector as described above along with the new developments in electricity generation, with well-chosen government policies US energy vulnerability in the 21st century will be even further reduced.

The displacement of one energy feedstock for another, as cited in the beginning of this paper, is a protracted process. From the discovery of coal in Europe in the thirteenth century, more than *six hundred years* elapsed before it could be said that coal-generated energy surpassed that contributed by wood. Given the problems and prospects discussed above, the approaching 21st century is likely to be witness to just this type of momentous change and – as is wont in our age – it is likely to occur at a considerably accelerated pace.

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Appendix

The environment

While the opportunities described are likely to enable the USA and other oil-importing developed economies to escape a major oil crisis over the next decade, these measures are unlikely to suffice as a long-term solution to the increasing global demands for oil in particular, and for fossil fuels in general. The recent high-level meetings held by government officials of the major fossil-fuel-consuming developed countries has provided yet another incentive for searching for alternatives to fossil fuels (including oil) as the main energy source for the world economy of the 21st century.

A number of recently released reports and government pronouncements on the environment have called for, at the very least, serious modifications in the use of fossil fuels by electric utilities, industry and the motor vehicle sector in the USA before the end of the century.[32] According to the *Wall Street Journal*,[33] polls indicate an increasing number of Americans favour improvements in the environment, regardless of costs. In fact, 57% of the global warming has been attributed to fossil fuel production and use.[34] The automobile sector, according to *The Economist*[35] generates more than 50% of the 'most dangerous ingredients of urban smog.' New clean air proposals recently announced by the Bush Administration,[36] call for: a 50% reduction, by the year 2000, of power plant emissions that cause acid rain; the production by US automobile manufacturers of a minimum of one million methanol-fueled cars by 1997; and legislation that would require gas stations to capture gasoline vapours at the pump. In fact, the Bush Administration has argued for nothing less than 'reconciling the automobile to the environment'.[37] The Bush Administration has reinstated the fuel efficiency standards (passed in 1975 and relaxed by the Reagan Administration) to achieve an average 27.5 mpg for all cars produced in 1990. According to the US Office of Technology Assessment,[38] an average of 33 mpg is technically feasible for cars produced in 1995, and current thinking in the US Congress and among environmental groups is to increase the fuel efficiency standard to 34–45 mpg by the year 2000.

California, which has the nation's dirtiest air, has recently formulated its ambitious plan that will enable it to comply with the standards set by the 1970 Clean Air Act. Buses and cars are to be electrified, fleets of ethanol- and methanol-fueled automobiles are to be deployed insuring that, by 1998, 40% of all cars will have the capability to burn alternative fuels.[39] While the technical ability to produce cars that are powered by natural gas, or even by electricity is not in doubt, the real problem is one of economics – in the production of and fuel-distribution for these alternatively-fueled vehicles.

As far as power plants are concerned, cutting emissions in half by the year 2000 will force the industry to choose among a number of alternatives: installing the necessary abatement equipment, substituting low-sulphur coal as a feedstock or turning to other sources of electricity, eg, nuclear or PV power.

As the evidence mounts to confirm that burning fossil fuels causes a warming of the planet and more and more regions begin to suffer the effects of acid rain, an internationally coordinated effort will be needed to reduce the rate of growth of emissions (if not their absolute levels) to insure that no single country has a competitive advantage from the environmental point of view. Recognizing that global environmental problems are intensifying because of increased use of fossil fuels, and that a global environmental policy will be needed was recently acknowledged at the annual summit (The First Green Summit) of the leaders of the major industrial countries held in Paris.

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